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ON THE INFORMATIVENESS OF THE SHOCK PULSE METHOD FOR CONTROLLING THE GEOCOMPOSITE CONSTRUCTIONS STRENGTH

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ПРО ІНФОРМАТИВНІСТЬ МЕТОДУ УДАРНОГО ІМПУЛЬСУ ДЛЯ КОНТРОЛЮ МІЦНОСТІ ГЕОКОМПОЗИТНИХ КОНСТРУКЦІЙ

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ОБ ИНФОРМАТИВНОСТИ МЕТОДА УДАРНОГО ИМПУЛЬСА ДЛЯ КОНТРОЛЯ ПРОЧНОСТИ ГЕОКОМПОЗИТНЫХ КОНСТРУКЦИЙ

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Annotation. This article shows the possibility of using the shock impulse method widely used in the building industry for the control of above-ground concrete structures in relation to elements of underground geocomposite protective constructions. Instead of amplitude, it is proposed to use the duration of the shock pulse as an informative parameter. This is explained by the fact that, with the constancy of the projectile design and the properties of the media contacting upon impact, the duration of the impact, depending on the speed of the impactor before the impact, will change very slightly, much less than the shock pulse amplitude. Thus, stabilization of the impact force is not required, which greatly facilitates the task. As a result of experimental studies performed in the laboratory on various mortar mixtures that harden, it was established that there is a close correlation relationship between two data arrays: the values of the shock pulse duration and the uniaxial compression strength. It was experimentally established that the power-law dependence of the set informative parameter decreases with an increase in the strength limit of the material under uniaxial compression. The reliability of the obtained regression equations is in the range of 0.82 - 0.9. The closest correlation between the strength characteristics and the duration of the shock pulse is observed for concrete. The possibility of assessing the concrete strength properties using the proposed method variant was investigated. Samples of hydraulic concrete were taken for testing, from which cubic-shaped samples with a rib of 100 mm were made. Unlike concrete, in the study of hardening mixtures, a range with low strength values was covered. However, in this case, a correlation was found between the strength and duration of the shock pulse. This shows the possibility of using the shock pulse method in the new version, with the previously unused informative parameter - the shock pulse duration for assessing the strength of mortar mixes that harden, which are widely used to create geocomposite constructions. It is shown, that the shock pulse method good recommending to yourself for strength properties assessment of materials in the natural conditions.

Keywords: shock impulse method, compression strength, geocomposite constructions.

Introduction. One of the promising ways to improve the sustainability of the workings located in a block-structured environment is the directional change in the properties of the rock massif by creating geocomposite protective constructions. The effectiveness of this design is determined by the validity of the selected parameters and quality control of its construction, as well as monitoring the current state of the system “support – massif”.

The creation of a geocomposite is achieved in various ways, for example, by injecting a solution that harden into the massif or by tamponage a mounting space, by cementation and concrete spraying, using bookmarks that harden, etc. One of such geocomposite construction’s elements is always mortar mix that harden [1-3].

Cementation of fractured rock massif is a traditional technical solution to increase its carrying capacity. In this case, the matrix and the reinforcing element are similar in their physical and mechanical properties. The key to improving the stability of a block massif in unequal component stress field is the adhesion of the material being injected into the cracks. In Ukraine, studies on the cementation of the rock massif for the conditions of mining enterprises and the development of an appropriate regulatory and regularity technical base are carried out, including at the Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine [4].

Under the category of geocomposite construction, the plot of the rock massif with tamponage also falls, since, in addition to filling the voids behind the enclosing shell, the cement slurry penetrates into the cracks between the blocks. Tamponage with the use of cement-based solutions is very effective for stabilizing the rock mass, both as an independent tool and in combination with others. Many organizations are engaged in research in the field of tamponage in Ukraine. A feature of the work performed at the Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine is the study of the effect of various additives influence on the strength and waterproofing properties of tamponage slurry that harden.

One of the main ways to create geocomposite constructions with nonmetallic reinforcing elements is injection hardening of the geological environment. In addition to the classical schemes of hardening the massif with fastening mixtures, both on the basis of cement binders and on the basis of polymer resins, began to pay more attention to the possibility of using injection rock bolt. Initially, its were used in construction to strengthen the soil strata, but at the present time its are also used to increase the bearing capacity of a strongly disturbed rock massif. Injection rock bolts are perforated tubular structures with a transitional device for injecting cement mortar or a polymer-based binder. The use of support elements of this type provides not only the “stitching” of layers, as in metal-polymer rock bolts, but also the fastening of a chaotic block structure.

As follows from the above, a wide range of materials is currently used for the implementation of reinforcing elements of geocomposite structures: from metals to polymers.

Recently, in connection with the ever-increasing complexity of solving the problem of energy, interest in the development of uranium deposits has increased significantly. At the same time, due to the increase in the depth of development, the deterioration of mining and geological conditions for the development of uranium deposits, difficult economic circumstances for uranium mining enterprises and, consequently, an increase in production costs, the issue of substantiation and improvement of technologies for maintaining mine workings, support elements and control their condition.

Methods. The widespread use on underground uranium-mining enterprises of bookmarks that harden, the introduction of new high-adhesive binders, reinforced concrete and steel-polymer supports, the combination of which creates a geocomposite constructions with unique properties in the rock massif, with a simultaneous intensification of mining operations, put forward new, more stringent requirements for monitoring and diagnostics the state of the geomechanical system "massif - support and protective constructions." When reinforcing the rock massif with the use of geocomposite constructions, the need arises for the operational control of their condition. Preferable for rapid assessment of the current strength of material that harden directly at the place of its use are non-destructive testing methods. Ukraine has a national standard DSTU B V.2.7-220: 2009, which regulates the means and methods of non-destructive testing for concrete. For it, developed a number of methods and means of rapid assessment of strength characteristics. But due to the peculiarities of performing control in underground conditions, not all methods can be effectively used. At present, the shock pulse method [5, 6] is quite successfully used to control the strength properties of concrete.

The application of the method, however, has its own characteristics, which impede the direct transfer of the technique developed for the control of concrete structures in above-ground conditions in mine conditions.

Therefore, the actual task is to adapt this methodological development to control the strength of hardening mixtures as elements of geocomposite protective – supporting constructions.

The author has developed a method and a means of assessing the strength of rocks and geocomposite constructions elements by the shock pulse method, which allows using it in underground conditions. This technique is based on the theoretically established correlation dependence of the ultimate strength for uniaxial compression and the shock pulse duration [7], which is expressed as follows:

$$\tau \approx 2{,}9\sqrt[5]{\frac{1}{V_0}\frac{m^2}{R}\left(\frac{1}{\rho_1 C_{p1}^2}+\frac{A^2}{\rho_2(\sigma_c+B)^2}\right)^2},$$

where τ – the shock pulse duration, ms; ρ_1 and ρ_2 – the density of the hammer material and the material under test, respectively, kg/m^3; V_0 – relative velocity of bodies at the initial moment of contact, m/s; R – the radius of the hammer's spherical surface, m; m - the mass of the hammer, kg; C_{p1} – the speed of the longitudinal wave of the hammer material, m/s; σ_c – ultimate strength for uniaxial compression, MPa; A and B – are constant values for a given test material.

This dependence is approximated as follows:

$$\sigma_c = A\cdot\tau^{-B}.$$

It should be noted that the essence of the method is as follows: a hammer with spherical surface hits the surface of the object, and the entire impact energy (excluding heat losses) is expended on elastic and plastic deformations of the material under study. As a result of plastic deformations, a dint is formed, and elastic – a reactive force arises.

The higher the plastic properties of the medium, the more part of the impact energy is spent on plastic deformations, the duration of the impact increases and its strength properties decrease. Conversely, the higher the elastic properties, the magnitude of the force increases, the duration of the impact decreases which indicates an increase in strength of the material. That is, in the case of a normalized impact, the magnitude of the reactive force and the duration of the impact can serve as indicators of the object's strength investigation, to which the blow is struck. However, it is technically difficult to measure the strength and duration of the strike.

To measure these quantities, an electromechanical transducer is included in the design of the hammer, which converts the mechanical energy of an impact into an electrical impulse. Amplitude will be proportional to the force, and time is proportional to the duration of the impact. Therefore, amplitude and time can serve as indirect strength characteristics of concrete or rock.

Results and discussion. The author has conducted experimental studies of the dependence of the duration of a shock pulse on the strength properties of geomaterials and mortar mixes that harden. The studies were performed on samples of basic litotypes of rocks of the Zakhidnyi Donbas region (coal, sandstone, mudstone, siltstone), Artemivskyi gypsum deposits and Kryvyi Rig iron ore deposits, as well as the most widely used geocomposite materials in mining.

An important role in the formation of geocomposite constructions is played by various mixtures that harden. Therefore, mixtures based on cement binder were investigated in order to establish the informativeness of the method for monitoring the hardening dynamics of the mortar mixture. Also considered options with the addition to the base mixture of various additives: "Spraikon", calcium chloride $CaCl_2$, "TsentramentN3" (plasticizer), clay.

To strengthen the rocks, the most common is relatively cheap material – cement mortar. In most cases, portlandcement is used, and in the presence of aggressive groundwater, aggressive-resistant cements are used: pozzolanic, slag portlandcement and others. To control the properties of cement slurries (setting time, sedimentation stability, water permeability), activating additives are used: ferric chloride, calcium chloride, sodium silicate. Adding bentonite clay to the solution in the amount of 5 % of the sand mass increases 3–4 times the sedimentation time of solid particles. Therefore, for tamponage the voids of the mounting space, it is advisable to use sands containing slurry inclusions to prepare the solution, which improves the pump ability of the mixture. However, a high content of clay in the solution (over 10 %) leads to a decrease in the strength of the cement stone.

In the work was used additive "Spraikon". This additive is based on portlandcement, reinforced with fibers and polymers and is designed to restore of the vertical and ceiling destroyed concrete. "Spraikon", mainly used for the restoration of concrete, is easily applicable to different types of cracks. Compressive strength after 28 days can reach 44 MPa. Also, for the preparation of the samples under study, we used an additive-plasticizer, a modified surfactant

"Tsentrament N3". This additive significantly reduces the consumption of water in the concrete mix, increases its mobility, gives greater homogeneity of the concrete mix and improves its workability.

To determine the strength properties of geocomposites, mixtures based on cement binder were investigated. Samples in the form of cubes were formed from the studied mortar mixture. The mixture that harden was poured into molds and kept for 3 days. After which the tests was conduct.

At the next stage of the experiment, of the shock pulse duration of the tested samples from mixtures that harden was determined at various stages of their hardening. Then samples were tested for uniaxial compression using a PSU-10 press in accordance with GOST 21153.2 – 84. After processing the results for different categories of materials, a value field was obtained showing the dependence of the “shock pulse duration – uniaxial compression strength”, and the regression equations were calculated.

The closest correlation between the strength characteristics and the duration of the shock pulse is observed for concrete. The possibility of estimating the strength properties of concrete using the proposed method was investigated. For testing, samples of hydrotechnical concrete were taken, from which samples of cubic shape with a 100 mm edge were made. The test results of hydraulic concrete are illustrated in Figure 1.

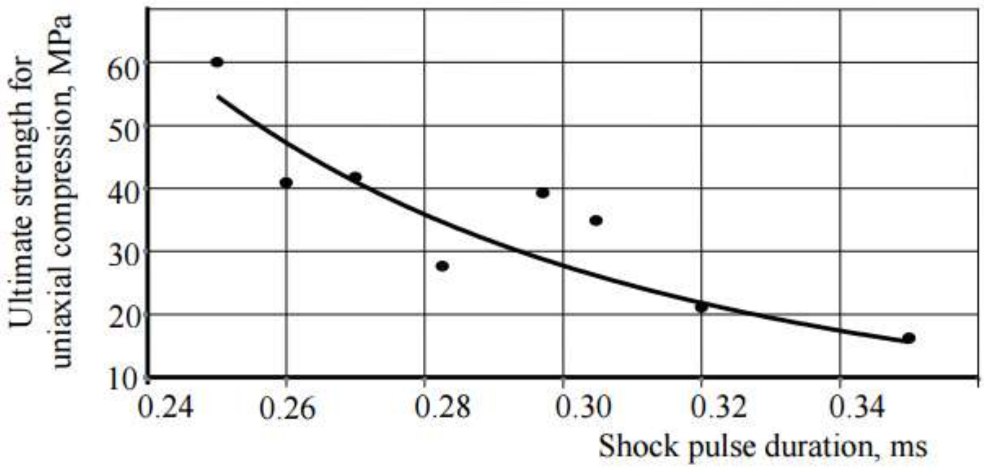

Figure 1 – Experimental relationship between the shock pulse duration and the ultimate strength for uniaxial compression for hydraulic concrete

The regression equation with a confidence of 0.9676 is:

$$\sigma_c = 0.3119\tau^{-3.7276}$$

Unlike concrete, in the study of mixtures that harden was covered range with low values of strength. However, and in this case, the presence of a correlation between the strength and shock pulse duration was established, as illustrated in Figure 2 and Figure 3.

The regression equations for arrays of data for mixtures that harden based on cement binder are presented in Table 1.

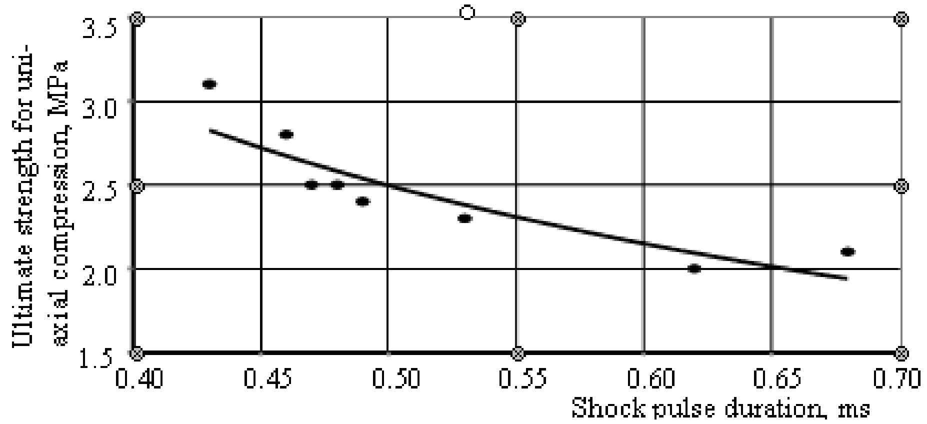

Figure 2 – Relationship between the shock pulse duration and the compressive strength

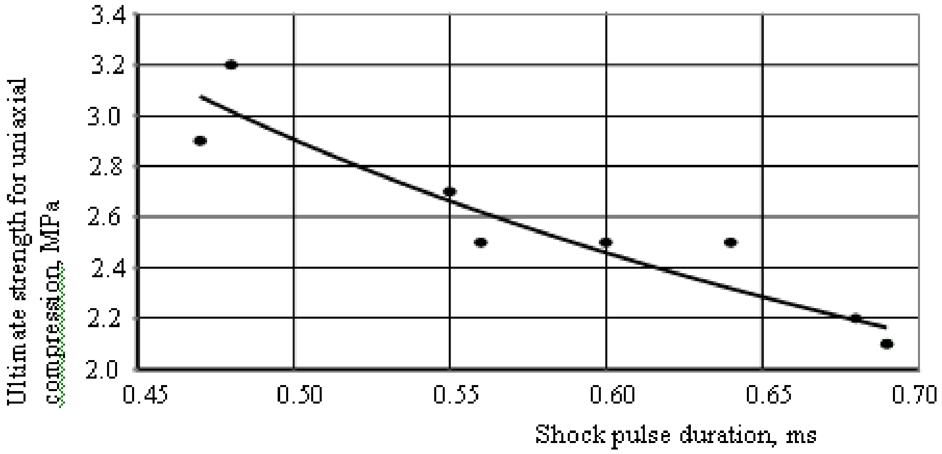

Figure 3 – Relationship between the shock pulse duration and the compressive strength for a water-sand-cement mixture that harden with the additive of $CaCl_2$

Table 1 – Regression equations to describe the dependence of the strength for mixtures that harden based on cement on the shock pulse duration

Test mixture	Regression equation	Equation reliability
Water-cement-sand without additives	$\sigma_c = 1.4154\tau^{-0.8189}$	0.8225
Water-cement-sand with the additive of calcium chloride	$\sigma_c = 1.5417\tau^{-0.9147}$	0.8971

Conclusions. Thus, as a result of experimental studies performed in the laboratory on various mortar mixtures that harden, it was established that there is a close correlation relationship between two data arrays: the values of the shock pulse duration and the uniaxial compression strength. The reliability of the obtained regression equations is in the range of 0.82 – 0.9. This shows the possibility of using the shock pulse method in the new version, with the previously unused informative parameter - the shock pulse duration for assessing the strength of mortar mixes that harden, which are widely used to create geocomposite constructions.

REFERENCES

1. Musiyenko, S. P. (2012), "To the development of technology and the construction of geocomposite security systems of mining", *Geo-Technical Mechanics*, no. 66, pp. 113–119.

2. Solodyankin, A. V., Kravchenko, K. V., Prokudin, A. Z. and Vygodin A. M. (2016). "Justification of rational parameters of the technology of tamponage mounting space", *Visti Donetskogo girnychogo instytutu*. no. 1, pp. 22–29.

3. Zubkov, A. A., Latkin, V. V., Neugomonov, S. S. and Volkov, P. V. (2014), "Perspective mounting methods of working in underground mines", *Gornyy informatsionno-analiticheskiy byulleten*, (10), 106–116.

4. Bulat, A. F. [and others] (2011), *Tekhnologichnyu reglament diagnostiki I vosstanovleniya zaglublennykh I podzemnykh sooruzheniy poverkhnostnogo kompleksa shakht na osnove sozdaniya geokompozitnykh konstruktsiy* [Technological regulation of diagnostics and renewal of depth and underground buildings of superficial complex of mines on the basis of technology of creation of geo-composit constructions], Monolit, Dnipropetrovsk, UA.

5. Korevitskaya, M. G., Tukhtaev, B. Kh. and Ivanov, S. I. (2013), "The use of non-destructive methods for monitoring the strength of high-strength concrete", *Promyshlennoe I grazhdanskoe stroitelstvo,* no. 1, pp. 53–54.

6. Petrov, A. V., Phaskhutdinov, A. A., Khaziakhmetov, M. Ph. and Yeremeeva, A. I. (2015), "Features of the application of the shock pulse method in the study of the brickwork state of the buildings and structures in use", *Ekspertiza promyshlennoy bezopasnosti I diagnostiki opasnykh proizvodstvennykh obyektov*, no. 5, pp. 170–171.

7. Skipochka, S.I., Palamarchuk, T.A., Sergienko, V. N. and Prokhorets, L.V. (2013), Rapid assessment of rocks strengthin the massif by the shock pulse method, *Metallurgicheskaya I gornorudnaya promyshlennost*, no. 2, pp. 74–77.

СПИСОК ЛІТЕРАТУРИ

1. Мусиенко С. П. К разработке технологии возведения геокомпозитных охранных систем горных выработок // Геотехническая механика: Межвед. сб. науч. тр. / ИГТМ НАН Украины. Днепропетровск, 2012. Вып. 66. С. 113–119.

2. Солодянкин А. В., Кравченко К. В., Прокудин А. З., Выгодин А. М. Обоснование рациональных параметров технологии тампонажа закрепного пространства // Вісті Донецького гірничого інституту. 2016. № 1. С. 22–29.

3. Зубков А. А., Латкин В. В., Неугомонов С. С., Волков П. В. Перспективные способы крепления горных выработок на подземных рудниках // Горный информационно-аналитический бюлетень. 2014. № 10. С. 106–116.

4. Булат А. Ф. и др. Технологический регламент диагностики и восстановления заглубленных и подземных сооружений поверхностного комплекса шахт на основе технологии создания геокомпозитных конструкций. Днепропетровск: Монолит, 2011. 48 с.

5. Коревицкая М. Г., Тухтаев Б. Х., Иванов С. И. Применение неразрушающих методов при контроле прочности высокопрочного бетона // Промышленное и гражданское строительство. 2013. № 1. С. 53–54.

6. Петров А. В., Фасхутдинов А. А., Хазиахметов М. Ф., Еремеева А. И. Особенности применения метода ударного импульса при исследовании состояния кирпичной кладки эксплуатируемых зданий и сооружений // Экспертиза промышленной безопасности и диагностика опасных производственных объектов. 2015. № 5. С. 170–171.

7. Скипочка С. И., Паламарчук Т. А., Сергиенко В. Н., Прохорец Л. В. Экспресс-оценка прочности горных пород в массиве методом ударного импульса // Металлургическая и горнорудная промышленность. 2013. №2. С. 74-77.

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Анотація. У даній статті показана можливість застосування широко використовуваного в будівельній промисловості для контролю наземних бетонних споруд методу ударного імпульсу стосовно до елементів підземних охоронних геокомпозитних конструкцій. В якості інформативного параметру замість амплітуди запропоновано використовувати тривалість ударного імпульсу. Це пояснюється тим, що при сталості конструкції ударника і властивостей контактуючих при ударі середовищ тривалість удару залежно від швидкості ударника перед зіткненням буде змінюватися дуже незначно, набагато менше, ніж амплітуда ударного імпульсу. Таким чином, не потрібно стабілізації сили удару, що набагато полегшує завдання. У результаті виконаних експериментальних досліджень у лабораторних умовах на різних розчинних сумішах, що твердіють, установлена наявність тісного кореляційного зв'язку між двома масивами даних: значеннями тривалості ударного імпульсу й межею міцності на одноосьовий стиск. Експериментально встановлене зменшення по статечній залежності встановленого інформативного параметра при збільшенні межі міцності матеріалу на одноосьовий стиск, Вірогідність отриманих рівнянь регресії перебуває в межах 0,82 - 0,9. Найбільш тісна кореляція між міцнісними характеристиками і тривалістю ударного імпульсу спостерігається для бетону. Була досліджена можливість оцінки міцнісних властивостей бетону з використанням запропонованого варіанту методу. Для випробувань були відібрані проби гідротехнічного бетону, з яких виготовили зразки кубічної форми з ребром 100 мм. На відміну від бетону, при дослідженні сумішей, що твердіють, був охоплений діапазон з невисокими значеннями міцності. Однак і в цьому випадку встановлена наявність кореляційної залежності між міцністю і тривалістю ударного імпульсу. Це показує можливість використання методу ударного імпульсу в новому варіанті, з інформативним параметром, що раніше не використовувався – тривалістю ударного імпульсу для оцінки міцності розчинних сумішей, що твердіють, які широко використовуються при створенні геокомпозитних конструкцій. Показано, що метод ударного імпульсу добре зарекомендував себе для оцінки міцнісних властивостей матеріалів у натурних умовах.

Ключові слова: метод ударного імпульсу, міцність на стискання, геокомпозитні конструкції.

Аннотация. В данной статье показана возможность применения широко используемого в строительной промышленности для контроля наземных бетонных сооружений метода ударного импульса применительно к элементам подземных охранных геокомпозитных конструкций. В качестве информативного параметра вместо амплитуды предложено использовать длительность ударного импульса. Это объясняется тем, что при постоянстве конструкции ударника и свойств контактирующих при ударе сред длительность удара в зависимости от скорости ударника перед соударением будет изменяться очень незначительно, намного меньше, чем амплитуда ударного импульса. Таким образом, не требуется стабилизации силы удара, что намного облегчает задачу. В результате выполненных экспериментальных исследований в лабораторных условиях на различных твердеющих растворных смесях установлено наличие тесной корреляционной связи между двумя массивами данных: значениями длительности ударного импульса и пределом прочности на одноосное сжатие. Экспериментально установлено уменьшение по степенной зависимости установленного информативного параметра при увеличении предела прочности материала на одноосное сжатие. Достоверность полученных уравнений регрессии находится в пределах 0,82 – 0,9. Наиболее тесная корреляция между прочностными характеристиками и длительностью ударного импульса наблюдается для бетона. Была исследована возможность оценки прочностных свойств бетона с использованием предлагаемого варианта метода. Для испытаний были отобраны пробы гидротехнического бетона, из которых изготовили образцы кубической формы с ребром 100 мм. В отличие от бетона, при исследовании твердеющих смесей был охвачен диапазон с невысокими значениями прочности. Однако и в данном случае установлено наличие корреляционной зависимости между прочностью и длительностью ударного импульса. Это показывает возможность использования метода ударного импульса в новом варианте, с неиспользуемым ранее информативным параметром – длительностью ударного импульса для оценки прочности твердеющих растворных смесей, которые широко используются при создании геокомпозитных конструкций. Показано, что метод ударного импульса хорошо зарекомендовал себя для оценки прочностных свойств материалов в натурных условиях.

Ключевые слова: метод ударного импульса, прочность на сжатие, геокомпозитные конструкции.

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